Table 4-1. Benefits and challenges of the FSS/LMDS spectrum protocol for LMDS and FSS systems.

	LMDS	FSS
Benefits	• Full 1000 MHz per service provider (1 reduced availability channel in Band B) • >99.9% availability in Band B for C/(N+I)=13 dB[1] [1] 99.9% CellularVision availability is achieved at a C/(N+I) of 8 dB and 99.7% Texas Instruments availability is achieved without use of the protocol • Dedicated 100 MHz in Band B (non-overlapped allocation 29.5-29.6 GHz) • Controlled spectral location of interference in each cell • Immediate deployment possible	• Full satellite bandwidth available everywhere (NO capacity reduction) • Operation on frequencies specified in satellite system design • Minimal impact on system design
Challenges	• Determination of ordered frequency list in each cell for maximum availability • Geographic channel plan information must be provided to FSS operators • Specific isolated cases of interference must be dealt with in Band B (see Section 4.5) • Reduced availability in a single channel for Band B • Reduced availability in Band B when simultaneously active FSS uplinks are clustered in a small number of LMDS cells • Reduced return link capacity in Band B • Required minimum separation distances to avoid all interference are still large • Reduced signal quality in the presence of interference • Enforcement of protocol	• Ordered frequency list information must be obtained from LMDS system operator • Transportability of Earth terminals limited without updating ordered frequency list • Additional signalling traffic on network due to additional database access (depending upon location of ordered frequency lists)

4.5 Resolving Specific Cases of Interference

Even with the use of the spectrum protocol, FSS uplinks will occasionally cause harmful interference to LMDS receivers. It is likely that this interference will occur repeatedly in isolated pockets throughout an LMDS deployment near locations where FSS uplinks with long and frequent high data rate access to the FSS network ("heavy FSS users") are located. These few terminals may cause repeated interference to a small group of LMDS subscribers. However, this effect cannot presently be assessed since the statistics of FSS usage are not available. There are several techniques that an LMDS service provider can use to resolve these isolated cases of repeated interference. A non-exhaustive list of possible mitigation options is given below.

- Adjust ordered frequency list of FSS uplinks located in affected LMDS service area
- Develop a priority ordered frequency list for "heavy FSS users" (dynamic reassignment)
- Install repeaters to boost LMDS signal level and point LMDS antennas away from an installed FSS uplink
- Increase hub transmitter power when technologically feasible and economically practical
- Realign, relocate, or replace LMDS subscriber antenna with an improved model
- Tailor LMDS service offering in that cell to avoid co-frequency operation with "heavy FSS users"
- Judicious landscaping
- Shielding of FSS Earth terminal antenna
- Negotiated inter-service agreement
- Time synchronization of digital LMDS transmissions with the duty cycle of FSS uplink transmissions

4.6 Chapter Summary

This chapter has detailed an FSS/LMDS Spectrum Protocol for FSS uplink frequency selection to reduce the likelihood of co-frequency interference exposures of LMDS receivers. The protocol directs the majority of FSS interference to specific portions of the frequency band on an LMDS cell-by-cell basis. Computer simulations of LMDS system availability show that when the protocol is implemented in FSS Earth terminals, LMDS availability in excess of 99.9% is achieved at a C/(N+I) of 13 dB in the presence of interference from either 15 T1 rate or 1440 16 kbps Teledesic Standard Terminals. Multiple conservative assumptions were used when computing the availability such that actual availability will be greater than the computed values. Operational aspects of protocol implementation were discussed indicating that this sharing solution does not impose an onerous burden on the system designs of either FSS or LMDS systems. In addition, the protocol is not a band segmentation protocol, but allows simultaneous access to the entire frequency band shared between the two services throughout the geographic region where both services are deployed. Implementation of the FSS/LMDS Spectrum Protocol, is the third major step in achieving a co-frequency sharing solution in the 27.5-29.5 GHz frequency band with 99.9% availability for both services without affecting FSS system capacity or requiring reduced antenna sidelobe levels.

5. Geometric Analysis of Specular Reflections

Calculation of interference from FSS uplinks into LMDS receivers is based upon a free space analysis with a line-of-sight path between the terminals. In the real world, it may be possible for an LMDS receiver to be sufficiently separated from an FSS uplink to avoid harmful interference via the direct path, but for harmful interference to be received via a specular reflection from a large object such as a building. One example of a geometry that could lead to the occurrence of the above scenario is shown in Figure 5-1. The left side of the figure shows an LMDS subscriber with a conceptual view of the potential interference zone around that subscriber receiver. Any FSS uplink located within that potential interference zone could cause harmful interference to the LMDS subscriber. The right side of Figure 5-1 shows the potential interference zone when a specularly reflecting surface intersects the potential interference zone around the LMDS receiver. It can be seen that the potential interference zone is "folded" at the specularly reflecting surface, causing a redirection of the potential interference zone. Hence, the FSS uplink indicated in the figure could potentially cause interference to the LMDS subscriber via the specularly reflected path, even though there is sufficient separation to avoid interference being received via the direct line-of-sight path between the two terminals.

Even though the presence of specular reflections creates the possibility for additional interference, the aggregate impact on the interference scenario is a statistical *decrease* in interference and an increase in LMDS system availability due to lossy reflections and overlap of the potential interference zone around an LMDS receiver. Notice that a portion of the potential interference zone on the left side of Figure 5-1 has disappeared in the right side of the figure. This occurs because the same surfaces that lead to interference being received via specular reflections from some locations serve to block interference received via the direct line-of-sight path from other locations. In addition, the size of the potential interference zone redirected by specular reflections will never be larger than the free space potential interference zone, and will almost always be smaller. It will be smaller because the specular reflection will nearly always be lossy, reducing the amount of received interference power and decreasing the required minimum separation distance along the specularly reflected interference path. In many cases, some of the redirected portion of the potential interference zone overlaps some of the free space potential interference zone such that the *total* area of the potential interference zone where an FSS uplink could cause harmful interference is reduced. Multiple specular reflections simply lead to multiple redirections of the potential interference zone, with the loss of each reflection leading to decreased required minimum separation distance along the interference path. A similar argument applies to the potential interference zone around LMDS hub antennas. The potential interference zone surrounding the receiver antenna is redirected via specular reflecting surfaces, but the statistical impact of these reflections is to increase system availability since these reflections are almost always lossy. Hence, the presence of specular reflections does not invalidate the availability computations in Chapters 3 and 4.

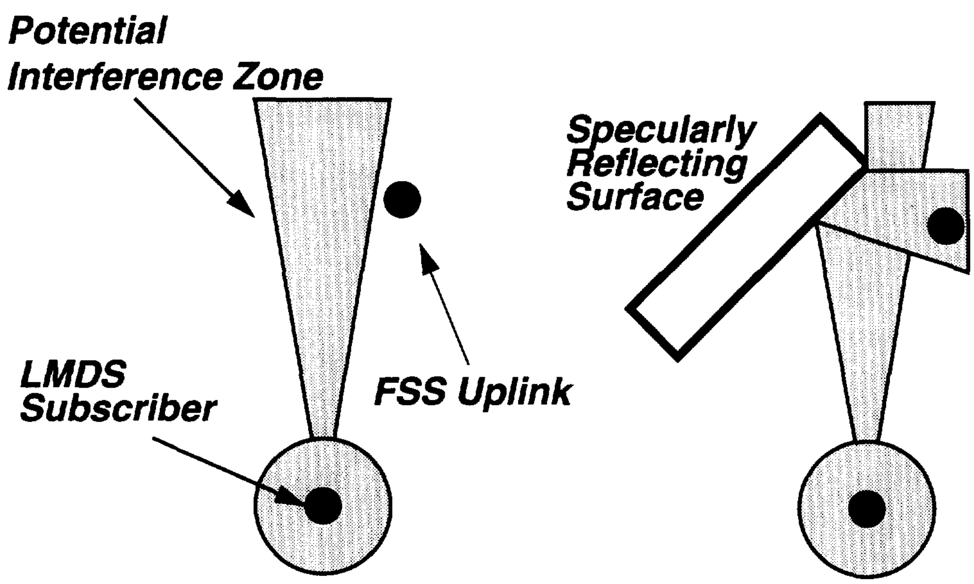

Figure 5-1. Conceptual view of the "folding" of the potential interference zone around an LMDS subscriber with a highly directional receiver antenna due to the presence of specular reflections.

6. CDMA Analysis

6.1 Overview

Previous analysis has shown that interference from FSS into LMDS is nearly always localized in both frequency and space. LMDS receivers usually experience interference over a relatively few number of channels from a small number of FSS uplinks. There is thus a potential benefit to LMDS from spreading the interference power from FSS over a wider bandwidth, if this does not increase the total amount of interference power. A given amount of FSS interference power which would cause harmful interference if concentrated in a single LMDS channel would be spread over many channels and not cause harmful interference in any. The spatial localization of interference limits the buildup of interference in any one LMDS channel from multiple FSS interferers. With some critical restrictions, this could be accomplished through use of direct-sequence CDMA as the multiple-access technique for FSS uplinks. The same effect could be realized by the use of CDMA by LMDS. The following sections discuss these possibilities and their limitations.

6.2 Need for CDMA Orthogonality

Both FSS and LMDS systems make intensive use of the frequency spectrum; users are "packed" tightly in both frequency and time. Both systems must thus use orthogonal multiple access techniques, where information sent to one user does not cause interference to information sent to another. Direct-sequence CDMA, however, is non-orthogonal; multiple-access channels create mutual interference with each other. The relative level of that mutual interference is given by the spreading gain, which is the ratio of the overall spread bandwidth to the information bandwidth of an individual channel. Since all other users cause interference to a given user, the capacity limit of a CDMA system is reached when this self-interference level lowers the user's signal-to-impairment ratio to its lowest acceptable value. It can be shown that the capacity of a single channel of non-orthogonal CDMA is lower than that of FDMA or TDMA by a ratio equal to the minimum required signal-to-impairment ratio. Since both FSS and LMDS use all available frequencies, neither system can use non-orthogonal CDMA as a multiple-access technique.

There are, however, CDMA techniques which can allow a limited number of users to access a given bandwidth orthogonally, without causing mutual interference. These use orthogonal functions such as Walsh functions for spreading sequences. Such an orthogonal spreading technique is used in the downstream direction of the IS-95 digital cellular radio standard. These techniques are equivalent to TDMA and FDMA as far as the number of users which are able to use a common frequency block. To maintain their capacity, either LMDS or FSS systems attempting to use CDMA must use orthogonal spreading sequences.

6.3 Use of CDMA

CDMA may be used by FSS systems to avoid the peaking of interference from FSS uplinks in individual LMDS channels. It would thus be advantageous for FSS to use the maximum possible spreading gain to disperse its interference most widely. For the Teledesic system, the maximum spreading bandwidth is 400 MHz. The maximum spreading gain for a

Teledesic 16 kbps terminal (225 kHz occupied bandwidth) would then be 32 dB. For a T1 rate terminal, the maximum spreading gain would reduce to 12 dB. The Teledesic Gigalink Terminal (TGT) is already transmitting a wide band signal, and would not benefit from spreading the spectrum. The bandwidth of a SPACEWAY satellite spot beam is 120 MHz. The maximum spreading gain for a T1 rate SPACEWAY terminal would then be 19 dB.

It would in principle be possible for FSS systems to replace their multiple access mechanism within an uplink satellite spot beam entirely with CDMA. All terminals would then access the satellite on a common frequency.

CDMA could in principle be used by LMDS systems to perform the entire multiple access function. The de-spreading process in an LMDS receiver would spread the power from a narrowband FSS interferer over all the available LMDS channels and thus reduce the equivalent interference power in a given channel. The overall affect would be equivalent to the use of CDMA with the same spreading gain by the FSS system. A serious drawback to the use of CDMA by LMDS systems, however, is its inability to interleave return links between forward links. The overall LMDS spectrum would have to be segmented between forward and return links. Since the spreading bandwidth would likely need to remain fixed, this reduces the possibility for dynamically allocating overall capacity between forward and return links and greatly restricts system flexibility.

6.4 Potential CDMA Improvements

CDMA facilitates FSS/LMDS frequency sharing by dispersing potential FSS interference through multiple LMDS channels. If that dispersal were uniform, the reduction of interference would be equal to the spreading gain. In practice, somewhat less energy is dispersed to the extremes of the spreading bandwidth, and the interference reduction would likely be less than the spreading gain by a few dB. As a very rough estimate, the improvement through the use of CDMA would be equivalent to a reduction in FSS antenna sidelobe level by the spreading gain (less a few dB).

6.5 Limitations on the Use of CDMA

While CDMA has the potential to significantly reduce the interference potential from FSS uplinks, it has several drawbacks. Because of its incompatibility with LMDS interleaved return links and dynamic capacity allocation, its use appears to be restricted to FSS uplinks. Because it uses wideband modulating waveforms, it requires larger guardbands to avoid interference from FSS uplinks into other services using adjoining bands. The use of CDMA is also incompatible with the spectrum protocol proposed here, so the benefits of both the spectrum protocol and the use of CDMA cannot be realized simultaneously. Finally, it imposes additional hardware complexity on FSS terminals and satellites. Further study is needed to better assess the impact of these limitations and the overall feasibility of the use of CDMA on digital systems where CDMA potentially offers advantages for facilitating FSS/LMDS frequency sharing.

7. Conclusions

This report shows that the Fixed Satellite Service (FSS) and the Local Multipoint Distribution Service (LMDS) can share the 27.5-29.5 GHz frequency band with 99.9% availability for both services. The 28 GHz 1994 28 GHz FSS/LMDS Negotiated Rulemaking Committee (NRMC) established in Docket 92-297 was not able to identify a co-frequency sharing solution during its 60-day existence. Three major steps have been taken to transform the results of the NRMC into a viable co-frequency sharing solution for the 28 GHz band. First, LMDS system descriptions have been slightly modified to operate continuously at full power with an occasional reduction in signal quality due to interference. Secondly, the LMDS system availability was computed based upon the technical characteristics and deployment scenarios provided by FSS and LMDS proponents to the NRMC. CellularVision availability is computed as 99.9% for a C/(N+I) of 11 dB, resulting in a picture quality of 'Passable to Fine' in the worst channel. The availability of the Texas Instruments system is 99.7%. The effect of an availability of 99.7% on a digital system with forward error correction is different than an analog system. The third major step is to implement an FSS/LMDS Spectrum Protocol for FSS uplink frequency selection to reduce the likelihood of co-frequency interference exposures between FSS uplinks and LMDS receivers. The protocol directs the FSS interference to specific portions of the frequency band on an LMDS cell-by-cell basis where the LMDS system accepts reduced availability. Computer simulations of LMDS system availability show that when the protocol is implemented in FSS Earth terminals, LMDS availability in excess of 99.9% is achieved in the presence of interference from either 15 T1 rate or 1440 16 kbps Teledesic Standard Terminals without requiring improved FSS uplink antenna sidelobe levels. An alternative third step to achieve co-frequency sharing with 99.9% availability is to require reduced sidelobe levels on FSS uplink antennas. This would reduce the size of the area around an FSS uplink where interference occurs when that uplink is transmitting. Multiple conservative assumptions regarding antenna sidelobe control, number and location of simultaneous FSS uplink transmissions, traffic distribution, propagation loss, and weather conditions were made in the calculations such that the actual availability will be significantly higher than the calculated availability.

It was shown that the presence of specular reflections does not lead to a decrease in LMDS availability. Interference from Teledesic Standard Terminals represents the worst case due to only partial band overlap between LMDS and SPACEWAY and the reduced geographic density of both SPACEWAY Earth terminals and Teledesic Gigalink Terminals (TGT) relative to the Teledesic Standard Terminals. Hence, LMDS availability in the presence of interference from SPACEWAY and TGTs will also be greater than 99.9%. Operational aspects of protocol implementation were discussed indicating that this sharing solution does not impose an unreasonable burden on the system designs of either FSS or LMDS systems. Furthermore, the FSS/LMDS Spectrum Protocol allows for simultaneous access to the entire shared portion of the frequency band everywhere for both FSS and LMDS; band segmentation is not required.

FSS and LMDS can share the 27.5-29.5 GHz frequency band with 99.9% availability for both services without affecting FSS system capacity.

8. References

[1] Report of the LMDS/FSS 28 GHz Band Negotiated Rulemaking Committee, September 23, 1994.

[2] Teledesic Corporation, ""Optimistic" Antenna Sidelobe Patterns Do Not Solve the Interference Problem Between FSS and LMDS," Motion for Leave to File Supplemental Comments, File No. 1-CF-P-94, December 2, 1994.

[3] CellularVision, "Motion to Proceed," CC Docket 92-297, Attachment A, January 26, 1995.

[4] Teledesic Corporation, "The Teledesic System Will Interfere With LMDS," NRMC-120, September 22, 1994.

[5] Teledesic Corporation, "Characteristics of Teledesic's Ka Band, Low Earth Orbit, FSS Network to Provide Global Voice, Data, and Video Communications," NRMC-24, July 26, 1994.

[6] W.J. Dixon and F.J. Massey Jr., *Introduction to Statistical Analysis*, McGraw-Hill, New York, 1983.

Appendix A. Minimum Required Separation Distance

A.1 Verification of Results with NRMC Working Group 1A Calculations

The calculation methodology described in the NRMC Working Group 1 report was coded into a C language computer program to compute the interference from FSS uplinks into LMDS receivers. From the computed interference levels, the required minimum separation distance between terminals to preclude harmful interference can be calculated. To insure that the results calculated here agree with the NRMC calculations, the input parameters specified in Table 2.3.1 of the Working Group 1 Report to the NRMC were input into the computer program, and separation distances were calculated.

Table A-1 compares the output of the computer program used here and the results presented in the NRMC WG 1 report for clear sky conditions. All distances in Table A-1 are given in miles. The first column specifies the LMDS receiver, the second column describes the characteristics of the interferer and the third column gives the portion of the LMDS antenna pattern directed at the interferer (main, side, back lobe). Columns 4-6 give the computed separation distances. Note that the NRMC calculations performed by Teledesic (Figure 6.2-1 through 6.2-23 in the Working Group 1 Report of [1]) do not compute the interference from a SPACEWAY interferer, and the calculations for a TI LMDS system do not include power control. The calculations performed by SPACEWAY (Table 6.1-1 in the Working Group 1 Report of [1]) for the TI system include power control. The largest differences between the results presented here and the results in the NRMC WG 1 final report can be traced to differences between the actual input parameters used to calculate the separation distances for the Working Group 1 Report and the values specified in Table 2.3.1 of the Working Group 1 Report. The largest differences are in receiver noise temperature; the remaining differences can be attributed to numerical round-off or slight differences in exact carrier frequency, and are small enough to confirm that the calculations presented here are correct.

Table A-1. Comparison of results from computer program used here with the results in the NRMC WG 1 report under clear sky conditions with distances in miles.

[1]The main beam of an LMDS subscriber antenna is small. Hence, an FSS uplink will infrequently be in the main beam of the LMDS subscriber antenna.

LMDS Receiver	FSS Transmitter	LMDS Antenna Direction	Required Separation (Teledesic)	Required Separation (Hughes)	Required Separation (Results Presented Here)
CellularVision subscriber	T1 TST	Main[1]	23.7	23.6	23.5
		Side	1.50	1.49	1.49
		Back	0.0751	0.0746	0.0747
	OC-24 TGT	Main[1]	1.96	1.94	1.96
		Side	0.123	0.123	0.123
		Back	0.00619	0.00606	0.00596
	SPACEWAY T1	Main[1]	N/A	25.5	26.6
		Side	N/A	1.61	1.68
		Back	N/A	0.0805	0.0842
CellularVision hub	T1 TST	N/A	0.504	0.504	0.501
	OC-24 TGT	N/A	0.0416	0.0416	0.0415
	SPACEWAY T1	N/A	N/A	1.64	1.70
TI 52 Mbps QPSK subscriber	T1 TST	Main[1]	4.07	14.55	4.25/15.06
		Side/Back	0.129	0.460	0.134/0.476
	OC-24 TGT	Main[1]	0.336	1.68	0.351/1.75
		Side/Back	0.0106	0.0532	0.0107/ 0.0557
	SPACEWAY T1	Main[1]	N/A	12.9	14.1
		Side/Back	N/A	0.409	0.445
TI 52 Mbps QPSK hub	T1 TST	N/A	0.324	1.156	0.338/1.196
	OC-24 TGT	N/A	0.0267	0.134	0.0272/ 0.140
	SPACEWAY T1	N/A	N/A	1.03	1.11

A.1.1 Teledesic Standard Terminal (16 kbps rate)

The Teledesic Standard Terminal operates at the minimum transmitter power required to maintain a constant E_b/N_o at the satellite receiver. The transmitter power is directly proportional to the transmitted bandwidth. Hence, during 16 kbps operation, the transmitter power is 96 times weaker than during 1.544 Mbps (T1) operation. Correspondingly, the minimum separation distance between a 16 kbps TST and an LMDS receiver is reduced. Table 2-1 summarizes the required minimum separation distances between a 16 kbps TST and an LMDS receiver. Additional improvements in required minimum separation distance when the CellularVision system implements the minor modifications described in Section 2.1 and requires a C/(N+I) of only 8-13 dB, or when the TI system does not implement power control, are comparable to those shown in Table 2-2 and Table 2-3. The new CellularVision subscriber antenna mask is described in Table A-3. The required separation distances shown in Table 2-1 are based on the peak interference density of the FSS uplink, and are thus conservative estimates. For a CellularVision hub-to-subscriber video channel, the difference between the upper (peak interference density) and lower (total interference power) interference bound is 19 dB (18 MHz/225 kHz), and for a 52 Mbps TI LMDS system, the difference is 23.6 dB (52 MHz/225 kHz). Since there is some evidence in NRMC tests [1] that interference is controlled more nearly by total power than by density, these minimum separation distances may be conservative by nearly a factor of 10.

Table A-2. Required separation distance (in km) between a 16 kbps Teledesic Standard Terminal and an LMDS receiver with the subscriber at the edge of the cell under clear sky/heavy rain conditions for different levels of FSS uplink antenna sidelobes (NRMC system descriptions).

[1] The main beam of an LMDS subscriber antenna is small. Hence, an FSS uplink will infrequently be in the main beam of the LMDS subscriber antenna.

LMDS Receiver	LMDS Antenna Direction	ITU Pattern (-38.2 dB)	Small TST (-40.0 dB)	Typical TST (-50.0 dB)
CellularVision Subscriber	Main[1]	4.7/6.2	3.8/5.7	1.2/3.5
	5° Side	0.6/2.4	0.5/2.1	0.2/1.0
	45° Side	0.3/1.6	0.2/1.4	0.08/0.59
	Back	0.015/0.137	0.011/0.113	0.004/0.036
CellularVision Hub	N/A	2.8/4.7	2.3/4.3	0.7/2.5
TI 52 Mbps QPSK Subscriber	Main[1]	2.5/5.5	2.0/5.1	0.6/3.0
	5° Side	0.2/1.5	0.2/1.3	0.05/0.53
	45° Side/Back	0.08/0.78	0.06/0.67	0.02/0.25
TI 52 Mbps QPSK Hub	N/A	0.20/1.50	0.16/1.32	0.05/0.56

Table A-3. Revised CellularVision subscriber antenna mask courtesy of M/A Com.

Azimuth Angle (ϕ) from Boresight (degrees)	Mask (dB relative to boresight gain)
0-7.2	$-3(\phi/2.5)^2$
7.2-12	-25.0
12-60	$-4-20*\log\phi$
60-180	-40.0

A.1.2 Teledesic Gigalink Terminal (OC-24 rate)

The Teledesic Gigalink Terminal (TGT) has an ITU antenna pattern sidelobe mask of 58 dB discrimination at 40°. Required minimum separation distances between a TGT and an LMDS receiver at cell edge are computed for the ITU antenna pattern mask and for a sidelobe discrimination of 68 dB in Table A-4. Improvement in required separation distance under clear sky conditions comparable to the case of TST interference is achieved when the CellularVision system increases the power per channel, improves the subscriber antenna, and reduces the required C/(N+I) threshold and when the Texas Instruments system does not implement power control, but instead always transmits at full power. Due to the small number of Gigalink terminals that are anticipated to be deployed, interference exposures from these terminals can be reduced by their judicious placement based on a detailed frequency coordination process as traditionally used by the point-to-point microwave community.

Table A-4. Required minimum separation distance (in km) between an OC-24 rate (1.24416 Gbps) Teledesic Gigalink Terminal (TGT) and an LMDS receiver with the subscriber at the cell edge under clear sky/heavy rain conditions (NRMC system descriptions).

[1] The main beam of an LMDS subscriber antenna is small. Hence, an FSS uplink will infrequently be in the main beam of the LMDS subscriber antenna.

LMDS Receiver	LMDS Antenna Direction	ITU Pattern (-58.0 dB)	Andrew SHX Parabolic (-68.0 dB)
CellularVision Subscriber	Main[1]	3.2/5.3	1.0/3.1
	5° Side	0.4/1.9	0.13/0.87
	45° Side	0.2/1.2	0.06/0.50
	Back	0.01/0.09	0.004/0.031
CellularVision Hub	N/A	0.07/1.22	0.02/0.51
TI 52 Mbps QPSK Subscriber	Main[1]	2.8/5.8	0.9/3.5
	5° Side	0.2/1.6	0.07/0.70
	45° Side/Back	0.09/0.87	0.03/0.34
TI 52 Mbps QPSK Hub	N/A	0.23/1.64	0.07/0.73

A.1.3 SPACEWAY Interferer (T1 rate)

When the interferer is a SPACEWAY uplink, the interference has a narrower bandwidth than the desired LMDS signal (except for CellularVision return links). Under this condition, the conservative calculations (based on peak interference density) overestimate the minimum separation distance required. For a T1 rate SPACEWAY uplink, the difference between the upper (peak interference density) and lower (total interference power) bound is 12.2 dB (18 MHz/1.08 MHz) for a CellularVision subscriber receiver, and 16.8 dB (52 MHz/1.08 MHz) for a TI receiver. While the actual effect of a narrowband interferer on a wideband signal is expected to be greater than computed with the lower bound, the large discrepancy between the upper and lower bound indicates that some reduction in the separation distances computed with the upper bound is likely. Table A-5 shows the required separation distance (km) between a T1 SPACEWAY uplink and an LMDS receiver with the subscriber located at the cell edge for different FSS antenna sidelobe performance levels and LMDS azimuth angles under clear sky and heavy rain conditions. Improvement in required separation distance under clear sky conditions comparable to the case of TST interference is achieved with the LMDS system modifications described in Section 2.1.

Table A-5. Required minimum separation distance (in km) between a SPACEWAY uplink and an LMDS receiver with the LMDS subscriber located at the cell edge under clear sky/heavy rain conditions. The upper bound of interference density was used to compute the separation distances (NRMC system descriptions).

[1]The main beam of an LMDS subscriber antenna is small. Hence, an FSS uplink will infrequently be in the main beam of the LMDS subscriber antenna.

LMDS Receiver	LMDS Antenna Direction	ITU Pattern (-47.0 dB)	Andrew Parabolic (-56.0 dB)	Andrew SHX Parabolic (-68.0 dB)
CellularVision Subscriber	Main[1]	42.9/7.4	15.2/4.9	3.8/2.5
	5° Side	5.4/3.0	1.9/1.7	0.5/0.6
	45° Side	2.7/2.1	1.0/1.1	0.2/0.3
	Back	0.1/0.2	0.05/0.08	0.01/0.02
CellularVision Hub	N/A	2.7/3.7	1.0/2.2	0.2/0.9
TI 52 Mbps QPSK Subscriber	Main[1]	22.6/6.6	8.0/4.3	2.0/2.1
	5° Side	1.7/1.9	0.6/1.0	0.15/0.31
	45° Side/Back	0.7/1.1	0.3/0.5	0.06/0.14
TI 52 Mbps QPSK Hub	N/A	1.8/2.0	0.6/1.0	0.2/0.3

Appendix B. Measured LMDS Video Signal Quality in the Presence of Interference

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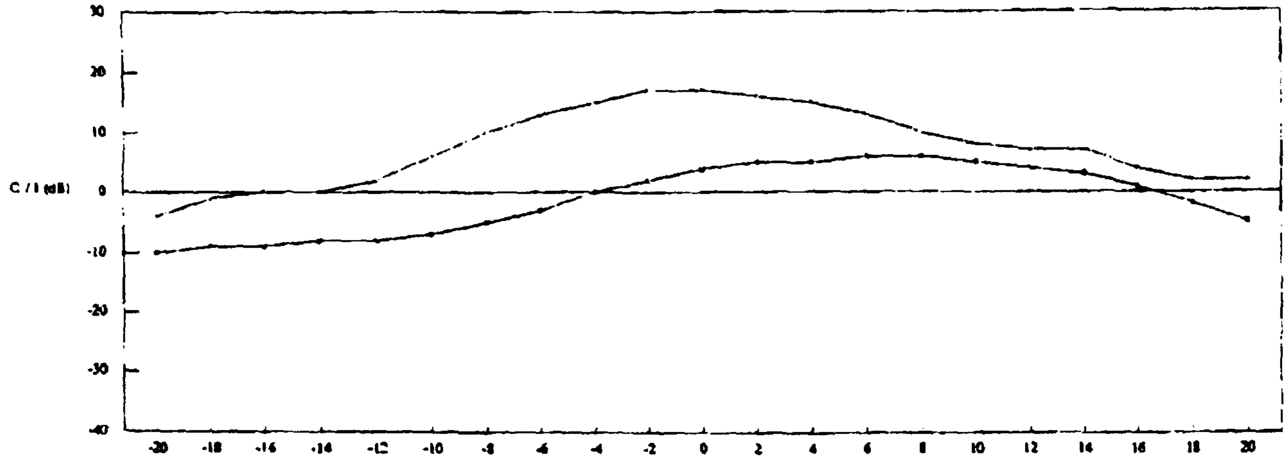
C/I TEMPLATE: MIN-MAX THRESHOLD OF INTERFERER

C/N: 31 dB
I MODULATION: FSS 28.5

	OFFSET(MHz)	20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	20
MAX	C/I RATIO (DB)	-10	-9	9	-8	-8	-7	-5	3	0	2	4	5	5	6	6	5	4	3	1	-2	-5
MIN	C/I RATIO (DB)	-4	-1	0	0	2	8	10	13	15	17	17	16	15	13	10	9	7	7	4	2	2

FSS 28.5 INTERFERENCE THRESHOLD MIN-MAX



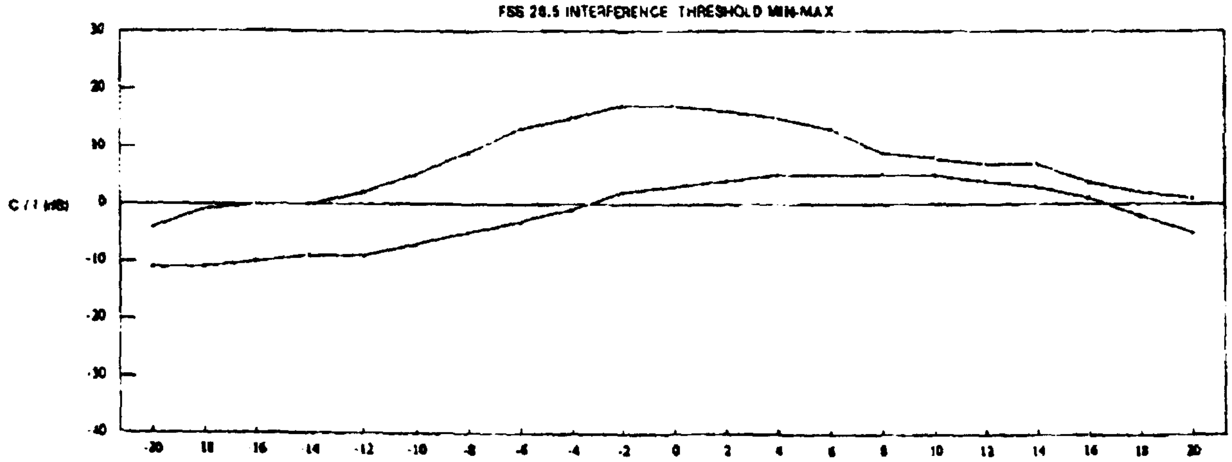
INTERFERER FREQUENCY OFFSET FROM FM CARRIER (MHz)

MAX = LEVEL AT WHICH INTERFERER RENDERS PICTURE TOLERABLE BUT DEGRADED
MIN = LEVEL AT WHICH INTERFERER IS FIRST PERCEPTIBLE TO VIEWER

C/N: 18 dB
I MODULATION: FSS 28.5

	OFFSET(MHz)	-20	-18	-16	-14	-12	-10	-8	6	-4	-2	0	2	4	6	8	10	12	14	16	18	20
MAX	C/I RATIO (DB)	-11	-11	-10	-9	-9	-7	-5	-3	-1	2	3	4	5	5	5	5	4	3	1	-2	-5
MIN	C/I RATIO (DB)	-4	-1	0	0	2	5	9	13	15	17	17	16	15	13	9	8	7	7	4	2	[illegible]

FSS 28.5 INTERFERENCE THRESHOLD MIN-MAX



INTERFERER FREQUENCY OFFSET FROM FM CARRIER (MHz)

MAX = LEVEL AT WHICH INTERFERER RENDERS PICTURE TOLERABLE BUT DEGRADED
MIN = LEVEL AT WHICH INTERFERER IS FIRST PERCEPTIBLE TO VIEWER

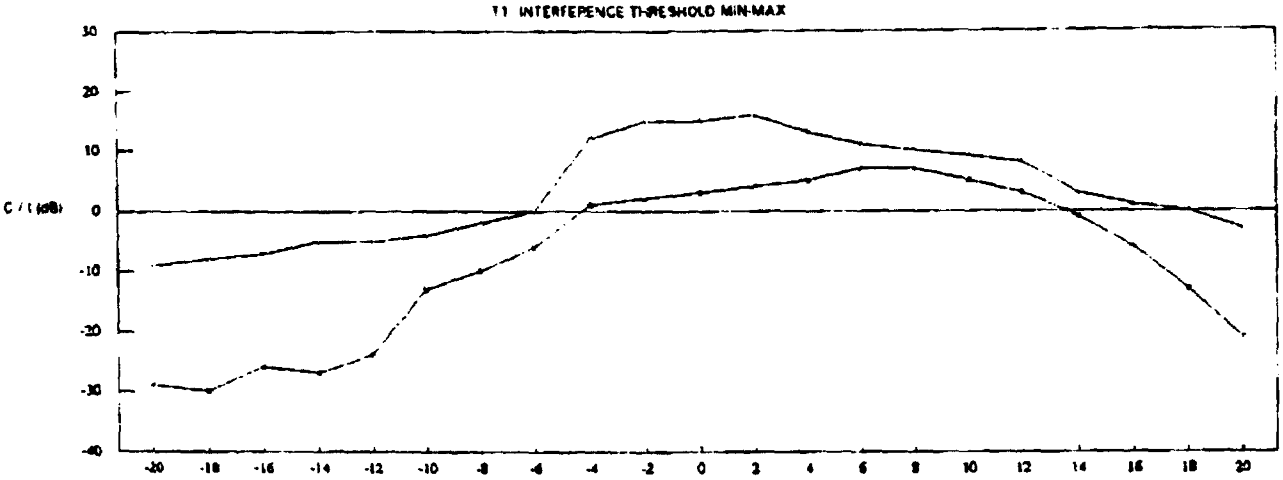
VIDEO SOURCE: VIDEO DISK

C/I TEMPLATE: MIN-MAX THRESHOLD OF INTERFERER

C/N=31 dB
I MODULATION: T1

	OFFSET(MHz)	20	-18	-16	-14	-12	10	-8	6	-4	-2	0	2	4	6	8	10	12	14	16	18	20
MAX	C/I RATIO (DB)	-29	-30	26	-27	-24	-13	-10	6	1	2	3	4	5	7	7	5	3	1	6	-13	21
MIN	C/I RATIO (DB)	-9	-8	7	-5	5	-4	-2	0	12	15	15	16	13	11	10	9	8	3	1	0	-3

T1 INTERFERENCE THRESHOLD MIN-MAX



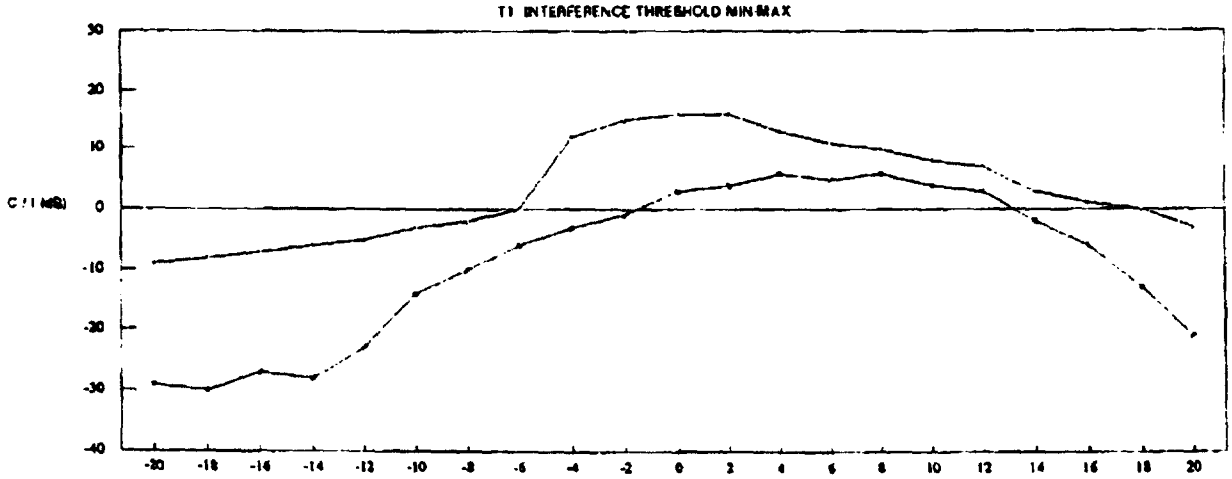
INTERFERER FREQUENCY OFFSET FROM FM CARRIER (MHz)

MAX = LEVEL AT WHICH INTERFERER RENDERS PICTURE TOLERABLE BUT DEGRADED
MIN = LEVEL AT WHICH INTERFERER IS FIRST PERCEPTIBLE TO VIEWER

C/N: 16 dB
I MODULATION: T1

	OFFSET(MHz)	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	20
MAX	C/I RATIO (DB)	-29	-30	-27	28	-23	-14	-10	-6	-3	-1	3	4	6	5	6	4	3	-2	-6	-13	-21
MIN	C/I RATIO (DB)	-9	8	-7	-6	-5	-3	2	0	12	15	16	16	13	11	10	8	7	3	1	0	-3

T1 INTERFERENCE THRESHOLD MIN-MAX



INTERFERER FREQUENCY OFFSET FROM FM CARRIER (MHz)

MAX = LEVEL AT WHICH INTERFERER RENDERS PICTURE TOLERABLE BUT DEGRADED
MIN = LEVEL AT WHICH INTERFERER IS FIRST PERCEPTIBLE TO VIEWER

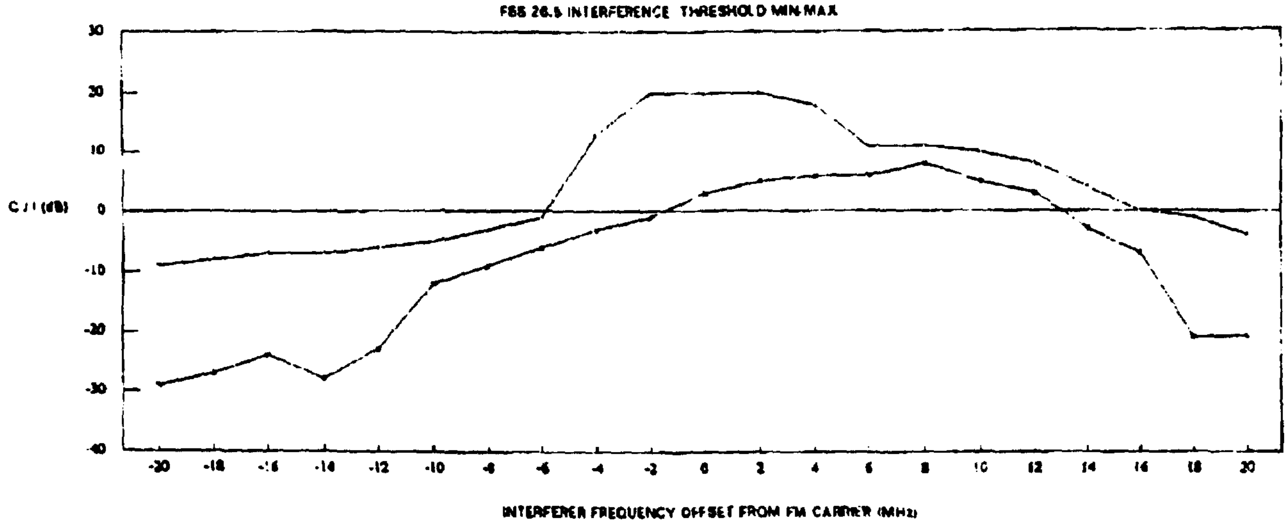
VIDEO SOURCE: VIDEO DISK

C/I TEMPLATE: MIN-MAX THRESHOLD OF INTERFERER

C/N 21 dB
I MODULATION: 64KB

	OFFSET(MHz)	-20	-18	-16	-14	12	-10	-8	8	-4	-2	0	2	4	6	8	10	12	14	16	18	20
MAX	C/I RATIO (DB)	-28	-27	-24	28	-23	-12	-9	-6	-3	-1	3	5	6	6	8	5	3	-3	7	-21	-21
MIN	C/I RATIO (DB)	-8	-8	7	-7	-6	-5	-3	-1	13	20	20	20	18	11	11	10	8	4	0	-1	-4

FSS 26.5 INTERFERENCE THRESHOLD MIN-MAX

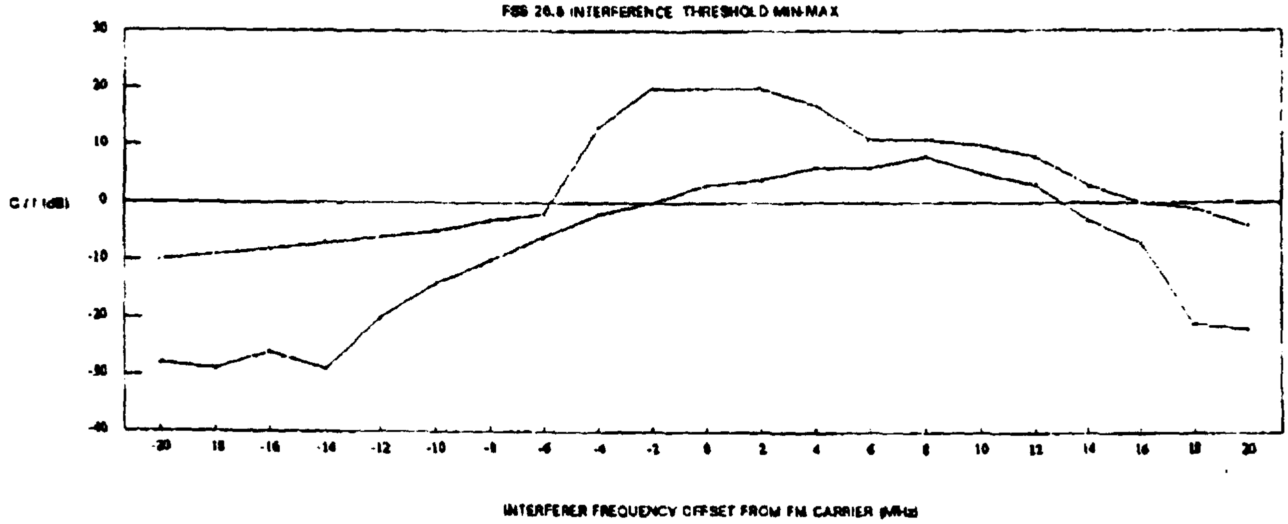


MAX = LEVEL AT WHICH INTERFERER RENDERS PICTURE TOLERABLE BUT DEGRADED
MIN = LEVEL AT WHICH INTERFERER IS FIRST PERCEPTIBLE TO VIEWER

C/N 18 dB
I MODULATION: 64KB

	OFFSET(MHz)	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	20
MAX	C/I RATIO (DB)	-28	-29	-26	-29	-20	-14	-10	-6	-2	0	3	4	5	6	8	5	3	-3	-7	-21	-22
MIN	C/I RATIO (DB)	-10	-8	-8	-7	-6	-5	-3	-2	13	20	20	20	17	11	11	10	8	3	0	-1	-4

FSS 26.5 INTERFERENCE THRESHOLD MIN-MAX



MAX = LEVEL AT WHICH INTERFERER RENDERS PICTURE TOLERABLE BUT DEGRADED
MIN = LEVEL AT WHICH INTERFERER IS FIRST PERCEPTIBLE TO VIEWER

VIDEO SOURCE, VIDEO DISK

Bellcore
Bell Communications Research

Co-frequency Sharing of the 28 GHz Band Between FSS and LMDS

Scott Y. Seidel

Washington, D.C.
April 24, 1995

Co-Frequency Sharing of the 28 GHz Band

Outline

- Steps used to achieve co-frequency sharing
  - Minor modification of LMDS system parameters
  - Development of methodology to statistically compute LMDS availability
  - Development of FSS/LMDS Spectrum Protocol to reduce the number of co-frequency interference exposures
- Results of statistical calculations
- Conclusion: Co-frequency sharing of the 28 GHz band is possible with 99.9% availability

Co-Frequency Sharing of the 28 GHz Band

LMDS System Modifications

- CellularVision:
  - Increase transmitter power per channel
  - Improve subscriber antenna mask
  - Reduce clear sky minimum required C/(N+I) to 8-13 dB ('Passable to Fine')
  - Area of interference suceptibility is reduced by roughly a factor of over 200
- Texas Instruments:
  - Operate continuously at full power without power control
  - Area of interference suceptibility is reduced by a factor of 20

Co-Frequency Sharing of the 28 GHz Band

Methodology to Compute LMDS Availability

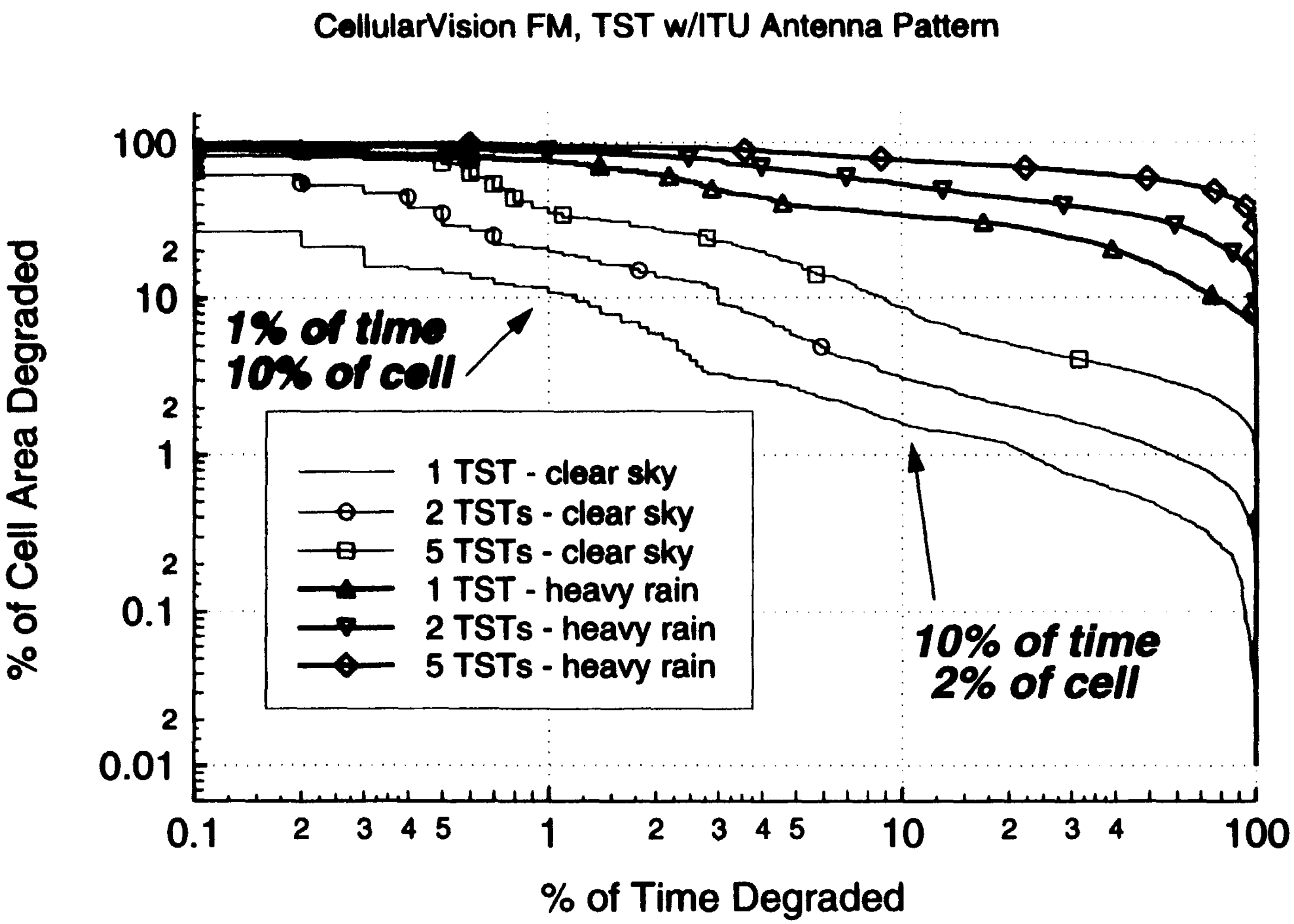
- NRMC system deployment descriptions
- Maximum satellite system capacity in a geographic area
- Factors modeled statistically
  - Locations of active FSS uplinks
  - Number of simultaneous uplink transmissions in an LMDS cell
  - Weather conditions
- Availability computed on an area basis across Teledesic 53 km x 53 km "cell" for CellularVision and Texas Instruments

Co-Frequency Sharing of the 28 GHz Band

Degradation Distribution

- The Degradation Distribution is a joint space-time measure of degradation that gives the statistical distribution of the percent of LMDS cell area that suffers from harmful interference based upon a Monte Carlo simulation of FSS uplink locations
- Presentation method first introduced by Teledesic
- Intermediate result

Co-Frequency Sharing of the 28 GHz Band
Degradation Distribution



Bellcore

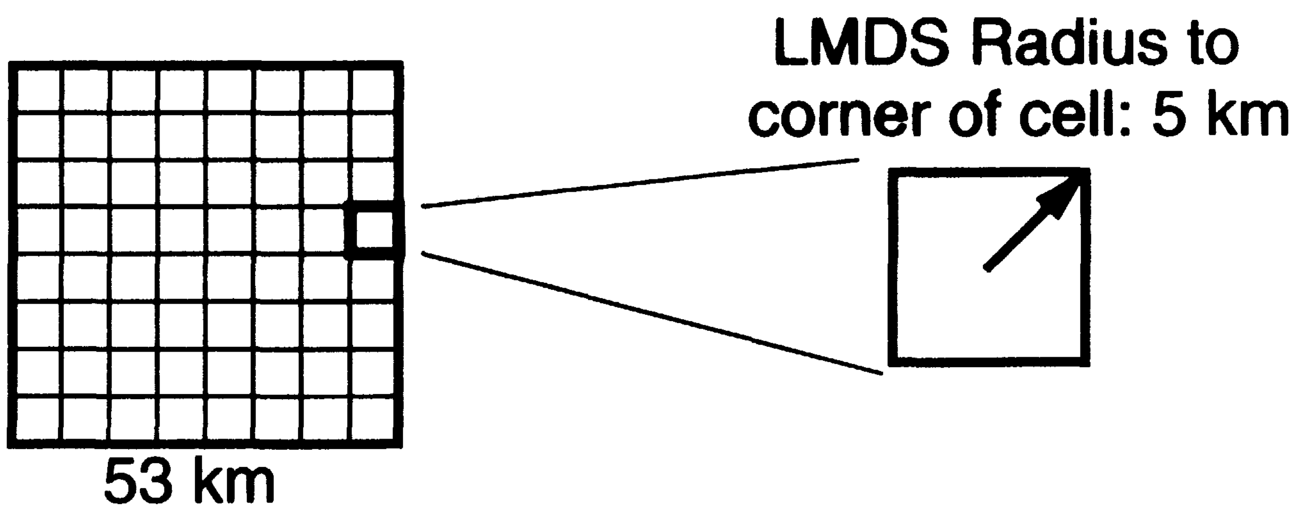
Co-Frequency Sharing of the 28 GHz Band

Availability Computation Road Map

- Compute single cell Degradation Distribution
  - Number of simultaneous T1 rate TST transmissions in LMDS cell
  - Weather conditions
  - FSS uplink (TST) sidelobe level
  - LMDS minimum required C/(N+I)
- Combine Degradation Distributions for clear sky (99%) and heavy rain conditions (1% of time for 99.9% rain rate of 15 mm/hr)

Co-Frequency Sharing of the 28 GHz Band
Availability Computation Road Map

- Consider a single Teledesic 53 km x 53 km "cell" with 15 simultaneous T1 uplinks
- 8 x 8 cell LMDS deployment within Teledesic "cell"



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